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TRACKING BLUEFIN TUNA COHORTS FROM EAST ATLANTIC SPANISH FISHERIES SINCE THE 1980s

E. Rodríguez-Marín[1], J.M. Ortiz de Urbina[2], E. Alot[2], J.L. Cort[1], J.M. de la Serna[2], D. Macias[2], C. Rodríguez-Cabello[1], M. Ruiz[1] y X. Valeiras[1]

SUMMARY

Relative abundance and mean size at age analyses were performed for the catches of three Atlantic Spanish fisheries, in search of an exceptionally abundant cohort in the recent history of the eastern Atlantic and Mediterranean bluefin tuna stock. Length distributions of baitboat fisheries, both in the Bay of Biscay and areas close to the Strait of Gibraltar as well as trap catches from the Spanish Atlantic coast were converted to age distributions using age length keys from calcified structures. Results do validate indirectly the ageing method. The 1994 cohort was clearly tracked for juveniles and young adults, 3 to 7 years old, in baitboat catches, and also for older specimens, 9 to 11 years old, in the trap fisheries. Based on these results, it is suggested that the juvenile and young adults fisheries in the western part of the Iberian Peninsula are interconnected between one another and with the Balearic Islands area of the western Mediterranean, as it is the nearest spawning ground described and because it is also supported by tagging and other studies.

RÉSUMÉ

Afin de trouver une cohorte exceptionnellement abondante dans la récente histoire du stock de ton rouge de l'Atlantique Est et de la Méditerranée, on a procédé à une analyse de l'abondance relative et de la taille moyenne par âge des captures réalisées par trois pêcheries espagnoles de l'Atlantique. Les distributions par tailles de deux pêcheries de canneurs dans le Golfe de Gascogne et dans les eaux proches du Détroit de Gibraltar, ainsi que les prises des madragues de la côte atlantique espagnole, ont été converties en âges à l'aide des clefs taille-âge obtenues à partir de la lecture de structures calcifiées. Les résultats valident indirectement la méthode de détermination de l'âge. La cohorte de 1994 affiche une forte indication présente chez les juvéniles et les jeunes adultes, de 3 à 7 ans, capturés dans les pêcheries de canneurs ainsi que chez les spécimens d'âge plus avancé, de 9 à 11 ans, pêchés à la madrague. Ces résultats suggèrent que les pêcheries de juvéniles et de jeunes adultes de la partie occidentale de la péninsule ibérique sont interconnectées entre elles ainsi qu'avec la zone des îles Baléares, en Méditerranée occidentale, étant donné qu'il s'agit de la zone de frai la plus proche et qu'il existe des indices de cette relation d'après les études de marquage et d'autres études.

RESUMEN

Para encontrar una cohorte excepcionalmente abundante en la historia reciente del stock de atún rojo del Atlántico este y Mediterráneo, se realizó un análisis de la abundancia relativa y la talla media por edad de las capturas de tres pesquerías atlánticas españolas. Las distribuciones de tallas de dos pesquerías de cebo vivo, en el Golfo de Vizcaya y en aguas próximas al Estrecho de Gibraltar, así como las capturas de las almadrabas de la costa atlántica española, fueron convertidas a edades mediante el uso de claves talla edad, obtenidas a partir de la lectura de piezas esqueléticas. Los resultados validan indirectamente el método de determinación de la edad. La cohorte de 1994 presenta una fuerte señal que pudo ser encontrada en los juveniles y adultos jóvenes, 3 a 7 años, capturados en las pesquerías de cebo vivo y también en especimenes mayores, 9 a 11 años, pescados con las almadrabas. Con esto resultados se sugiere que las pesquerías de juveniles y adultos jóvenes de la parte occidental de la península Ibérica están interconectadas entre ellas y con el área de las Islas Baleares, en el Mediterráneo occidental, puesto que es la zona de puesta más próxima y porque también hay evidencias de esta relación mediante el marcado y otros estudios.

KEYWORDS

Atlantic bluefin tuna, Thunnus thynnus, year-class, catch at age, coastal fisheries connection, migrations

[1] Instituto Español de Oceanografía. Centro Oceanográficos de Santander. Apdo. 240. 39080 Santander. Spain. rodriguez.marin@st.ieo.es
[2] Instituto Español de Oceanografía. Centro Oceanográfico de Fuengirola. Apdo. 285. 29640 Málaga, Spain.

1. Introduction

An exceptionally abundant cohort or year class is a cause for celebration for any fisheries scientist, as it indeed is for any fisherman. The strong signal of a cohort of this kind permits the study of its abundance in relation to other factors, such as denso-dependence phenomena, oceanographic characteristics at the time of its birth or its recruitment to the fishing area, and predator-prey relationships, for example. In addition, an indirect validation of growth can be made and the analysis of cohorts or structured models at age used in the assessment of populations can be calibrated.

In the Atlantic bluefin tuna (ABFT) *(Thunnus thynnus*) stock assessment in 2002 some signals of an exceptionally strong year class were found in the estimated eastern stock number by size (from VPA) and in the normalised relative index of abundance from baitboat in the Bay of Biscay (Anon. 2003; Rodríguez-Marín *et al*. 2003). Estimates of year class size from the base-case western Atlantic assessments conducted in 2000 and 2002 showed similar strong signals, but it was also shown that the tendency for large year classes estimated in one assessment was not sustained in the next (Anon. 2003). Despite the identification of several strong year classes since 1970, that of 1994 stands out with a strong signal in both Atlantic stocks, though it is stronger in the eastern and Mediterranean stock, and still appeared prominently in the 2006 assessment, in which the longline relative abundance index for ages 10+ confirmed past indications of a relatively strong year class in 1994 (Anon. 2007).

An exceptionally abundant year class should be easily identifiable in the catch at age matrix (CAA) of this stock, however in the case of the eastern and Mediterranean bluefin tuna stock there are several factors that affect the CAA construction, among them the following: general misreporting, undersized misreporting, high number of substitutions, the effect of combined gears selectivity pattern and the annual variations in these factors. For this reason this paper proposes the verification of the existence of an exceptionally strong year class in the recent history of the Eastern and Mediterranean bluefin tuna stock by searching for this signal directly in the abundance of catches in the Atlantic bluefin tuna fisheries. We also put forward the following working hypothesis: If we find an exceptionally abundant year class, we should be able to follow this 'signal' in nearby fisheries or in fisheries connected by Atlantic bluefin tuna movements.

2. Material and methods

We selected three Spanish Atlantic fisheries that have significant catches and have been adequately size sampled: baitboat in the Bay of Biscay, Atlantic traps and baitboat in the Strait of Gibraltar **(Figure 1)**. In order to find an exceptionally abundant year class in all of these three fisheries, we need to know if these fisheries are connected by Atlantic bluefin tuna migrations. The species' movements between the western Mediterranean Sea and both the Ibero-Moroccan Bay and the Bay of Biscay have been described by many authors: Sella (1929), Lozano Cabo (1959), Rodríguez-Roda (1964), Aloncle (1964), Sarà (1979), Lamboeuf (1975), Brethes (1979), Cort (1990). In the update made by Rodríguez-Marín *et al*. (2008) using the analysis of over 700 recaptures from around 15 000 conventionally tagged ABFT since the late 1970s, both the contribution of bluefin tuna juveniles to the eastern Atlantic from the nursery areas in the Mediterranean and the exchange between the Atlantic coast of Morocco and the Bay of Biscay are corroborated. **Figure 2** shows the relative recapture rate (recaptured/tagged*100) by tagging area and time at liberty around the Iberian Peninsula (reelaboration of data from Rodriguez-Marin *et al*. (2008)). We can therefore infer that the three fisheries appear to be connected by the migratory movements of Atlantic bluefin tuna.

Length distributions of baitboat fisheries, both in the Bay of Biscay and areas close to the Strait of Gibraltar, as well as trap catches from the Spanish Atlantic coast were converted to age distributions using age length keys (ALKs) obtained by readings of sections of the first ray of the first dorsal fin. Four series of ALKs were available: (1) Annual ALKs for the Bay of Biscay from 1985 to 2006; (2) ALK obtained from catches of Spanish Atlantic fisheries (Rey and Cort, 1984); (3) ALK obtained from the catches of the Atlantic trap of Barbate in 1984 (Cort, 1991); and (4) ALK obtained from specimens sampled in Atlantic traps in 1990 (Rodríguez-Marín *et al*., 2004).

A preliminary analysis of the length to age conversion using the Bay of Biscay ALKs was undertaken. Annual ALKs were reviewed by the analysis of the size distribution at age matrix obtained by applying the ALK to the respective yearly catch length distribution. To convert into age the length distributions from Bay of Biscay, the corresponding annual ALKs were applied. For traps and Strait of Gibraltar baitboat fisheries, a pooled ALK computed with all data available were applied. **Table 1** summarises the number of spine sections used in the annual ALKs and pooled ALK and **Table 2** presents the total pooled ALK. In **Figure 3**, **Figure 4** and **Figure 5**, a description of each fishery and the ageing process is presented, including the age composition of the catch and the gear selectivity pattern.

Relative abundance, expressed as standardised catch at age, and mean size at age analyses were carried out in search of an exceptionally abundant cohort. To observe the sensitivity of the catch matrix of each fishery to the method used to convert to ages, the standardised catch at age matrix was built using annual and pooled ALKs. **Figure 6** was developed to compare length at age from the pooled ALKs with the currently used growth curve for the east Atlantic and Mediterranean stock (Cort, 1991). Both Bay of Biscay pooled and total pooled ALKs give slightly higher values in respect of the Cort's curve, differing few centimetres by age. Differences in growth between the 1994 cohort and the mean of the remaining Bay of Biscay cohorts were analyzed by applying the "overall test of coincident curves" (Chen *et al*., 1992) and "Kimura's likelihood ratio test" (Kimura 1980).

3. Results

The standardised catch at age and the mean fork length at age and year of the Bay of Biscay baitboat fishery are shown in **Figure 7** and **Figure 8**, respectively. The 1994 year class stands out as an extraordinarily strong cohort and can be easily tracked through the years from age 3 to age 7. The cohort is more clearly defined when converting lengths at age using the annual length-age keys instead of a combined one **(Figure 7)**. The 1994 year class shows some of the lower length values of the series **(Figure 8)**. **Figure 9** presents the growth curves of the Bay of Biscay cohorts fitted to ages from 1 to 5, which are the best represented ages in catches. Lower growth is observed in the 1994 cohort, though this difference is not significant in relation to the mean value of the remaining cohorts.

The signal of the 1994 cohort is seen in the standardised catch proportion at age of the Strait of Gibraltar baitboat fishery, shown in **Figure 10**. There is an anomalous yearly effect due to the large variations in the length composition of the catch, however the 1994 cohort can be tracked in ages from 3 to 6 years, which are the best represented in the fishery in the study period. In **Figure 10** a better definition of the 1994 year class can be seen when applying annual ALKs than when using the combined ALK. The mean length at age of catches is represented in **Figure 11**. No differences are observed in the mean length of the 1994 cohort with respect to the other cohorts.

The 1994 year class is also identified in the standardised catch proportion at age of the Spanish Atlantic traps **(Figure 12)**. Ages 9 to 11, which are well represented in the catches of the trap **(Figure 5)**, are those that show this abundance signal. It may be that the signal of this cohort could be found in older year classes, but information of lengths from the traps from 2005 is unavailable. No differences are seen in the mean length at age of the 1994 cohort **(Figure 13)**.

4. Discussion

The 1994 cohort was clearly tracked for juveniles and young adults, 3 to 7 years old, in Bay of Biscay and Strait of Gibraltar baitboat catches, and also for older specimens, 9 to 11 years old, in the Atlantic trap fisheries. The gear selection pattern of these fisheries led to these ages being well represented in each fishery. Size sampling and age conversion made it possible to track the cohort down the years, though as might be expected annual ALKs were more appropriate than the pooled one. This may be the reason why this 1994 year class is best observed in the Bay of Biscay fishery, as it is the only one for which annual keys are available and therefore substitutions in the study period were not necessary. It is highly recommended that annual keys are available for each fishery in order to build a good catch at age matrix.

Results do validate indirectly the ageing method, or which comes to the same thing, the ALKs built by the age interpretation based on the observation of sections of the first ray of the first dorsal fin. Therefore these findings are also an indirect validation of the first years of the growth curve currently used for the east ABFT stock, since few differences were found between the ALKs employed in the present study and this curve.

The 1994 cohort present in the Bay of Biscay shows lower growth than the remaining cohorts, and although we did not find significant differences with the rest of the cohorts, it may indicate a denso-dependent effect. Nevertheless, other factors such as the availability of prey and oceanographic factors cannot be ruled out and further research is required.

Tracking the 1994 cohort in different fisheries over the years confirms the importance of this year class and indicates the close relationship between these fisheries. That is to say, its catches seem to come from the same ABFT population. This finding, together with the information from conventional and electronic data, existing knowledge of fisheries, areas of spawning (the Balearic Island waters being the nearest spawning ground described) and feeding, and stable isotopes analysis (Cort, 1990; Mather *et al.*, 1995; Fromentin and Powers, 2005; Rooker *et* al., 2007; Rooker *et al*., 2008), leads us to infer the close relationship between juveniles and young adults from the west Mediterranean and the northeast Atlantic. For this reason, we can also conclude that the relative abundance index for juveniles in the Bay of Biscay represents a fraction of the population of the east Atlantic and west Mediterranean.

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Table 1. Description of the source and number of sections of the first ray of the first dorsal fin used to build the age length keys for conversion to ages.

Sampling area	Bay of Biscay	Atlan.Fisheries	Atlantic Traps	Atlanic Traps	
Sampling year	1979-2007	1983	1984	1990	Total
Source	Present study	Rey&Cort (1984)	Cort (1991)	Rguez-Marin et al (2004)	Pooled
Age 1	863	51			914
Age 2	1233	44			1277
Age 3	1038	47			1085
Age 4	779	42		1	822
Age 5	497	41		1	539
Age 6	245	19	3	2	269
Age 7	126	28	7	2	163
Age 8	48	18	7	10	83
Age 9	21	3	23	6	53
Age 10			24	17	41
Age 11			38	16	54
Age 12			21	9	30
Age 13			21	11	32
Age 14			19	12	31
Age 15			21	13	34
Age 16			3	9	12
Age 17+			5	4	9
Total	4850	293	192	113	5448

Table 2. Total pooled ALK for ages 1 to 17 comprising all age length keys (ALKs) used in the present study: annual ALKs for the Bay of Biscay from 1985-2006, ALK obtained from catches of Spanish Atlantic fisheries (Rey & Cort 1984), ALK obtained from the catches of the Atlantic trap of Barbate in 1984 (Cort 1991) and ALK obtained from specimens sampled in Atlantic traps in 1990 (Rodríguez-Marín *et al*. 2004).

Size \ Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
45-49	1																	1
50-54	35																	35
55-59	224																	224
60-64	345																	345
65-69	251	16																267
70-74	55	125																180
75-79	3	388	2															393
80-84		448	11															459
85-89		243	52															295
90-94		45	188															233
95-99		11	263	8														282
100-104		1	271	23														295
105-109			191	37														228
110-114			89	87														176
115-119			18	161														179
120-124				204	1													205
125-129				161	19													180
130-134				80	62	1												143
135-139				39	78	1												118
140-144				11	108	18												137
145-149				11	118	31												160
150-154					93	48	3											144
155-159					41	56	9											106
160-164					13	57	14											84
165-169					6	29	20	4										59
170-174						13	43	11	1									68
175-179						6	33	11	0									50
180-184						9	26	13	8	1								57
185-189							8	21	11	3								43
190-194							6	12	11	4	2							35
195-199							1	6	12	8	3							30
200-204								2	5	4	4							15
205-209								2	1	6	7							16
210-214								1	2	5	4	3	1					16
215-219									2	5	11	8						26
220-224										3	9		4	3				19
225-229											9	5	5	1	1			21
230-234										1	4	6	10	4	2			27
235-239										1		6	2	2	3			14
240-244											1	1	6	3	6	2		19
245-249												1	1	8	3	1		14
250-254													2	4	7	2	1	16
255-259													1	3	6	1	1	12
260-264														1	2	1	1	5
265-269														1	2			3
270-274														1	2	3	1	7
275-279																1	1	2
280-284																1	1	2
285-289																	1	1
290-294																	1	1
295-299																		0
300-304																	1	1
Total	914	1277	1085	822	539	269	163	83	53	41	54	30	32	31	34	12	9	5448

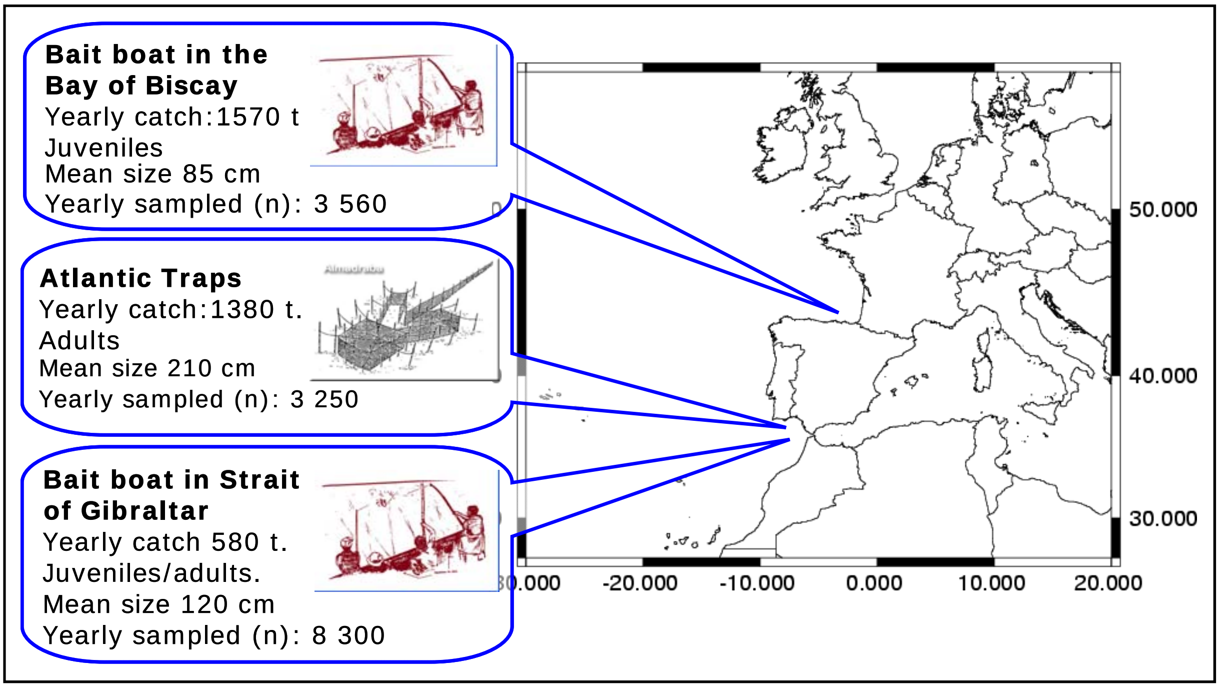

Figure 1. Location and general description of the selected ABFT Spanish Atlantic fisheries during the study period (1980s to the present).

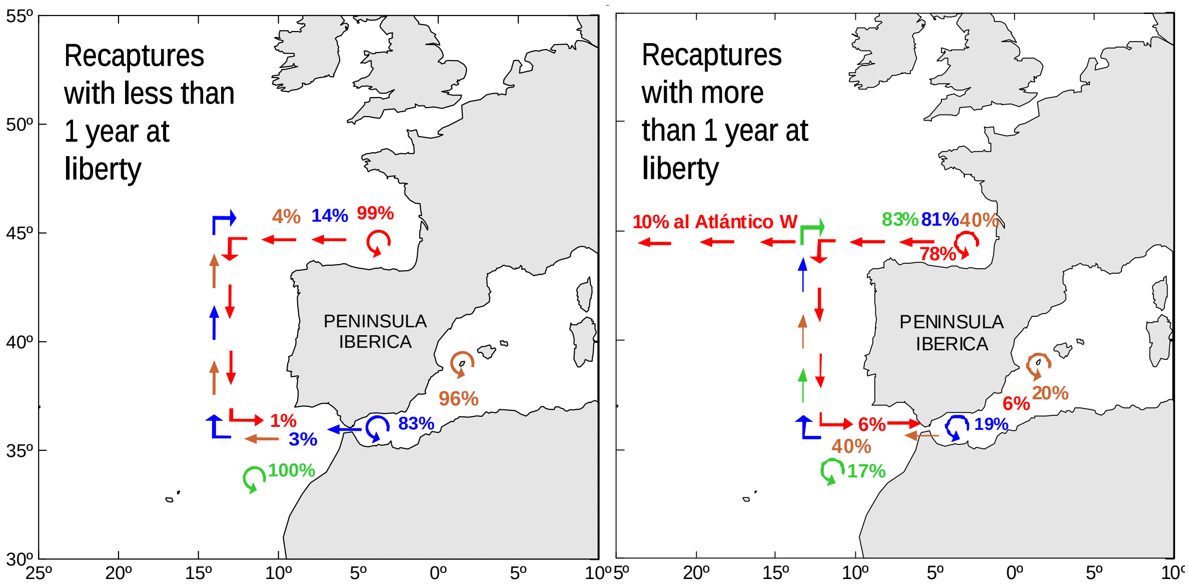

Figure 2. Maps representing juvenile tuna migrations around the Iberian Peninsula as a function of the time elapsed between tagging and recovery, on the left those with less than 1 year at liberty and on the right those with more than one year at liberty. Numbers and colours indicate the percentage of recaptures according to where they had been tagged: red in the Bay of Biscay, green off the Moroccan Atlantic coasts, blue in the Alboran Sea and brown around the Balearic Islands.

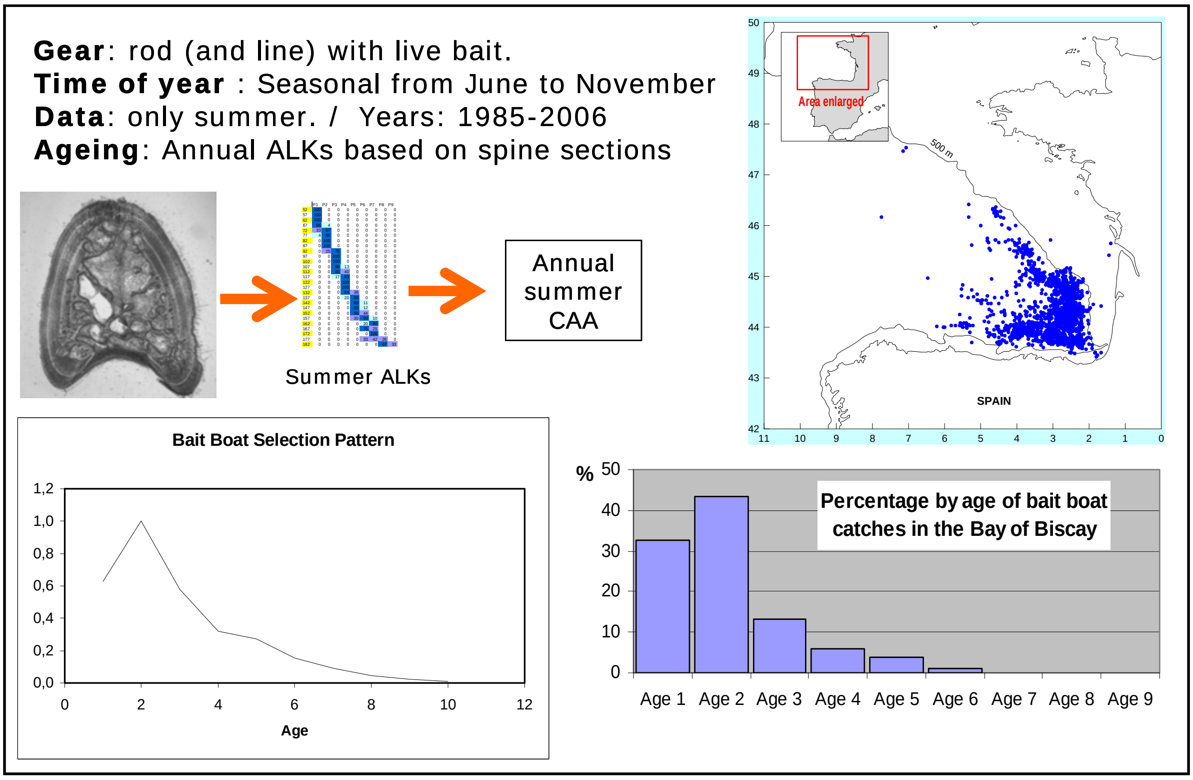

Figure 3. Description of the Bay of Biscay baitboat fishery and the ageing process.

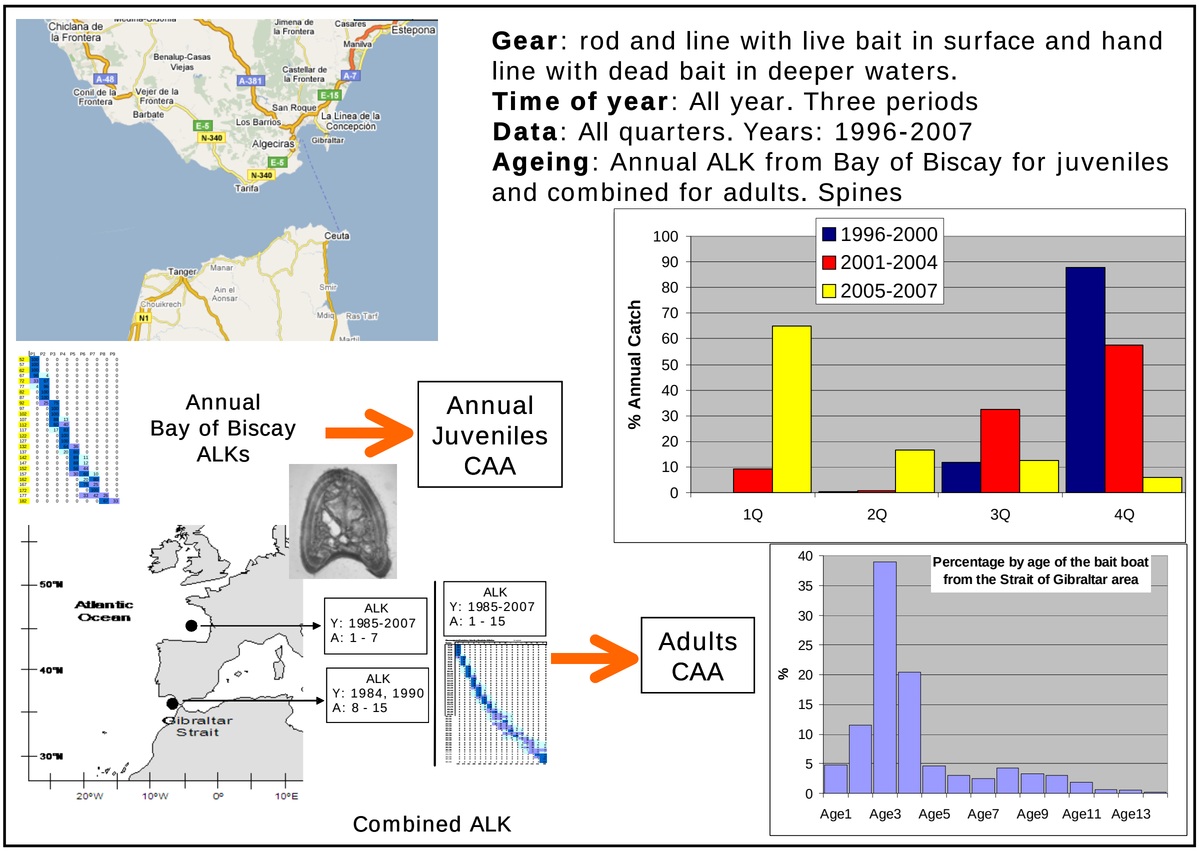

Figure 4. Description of the Strait of Gibraltar baitboat fishery and the ageing process.

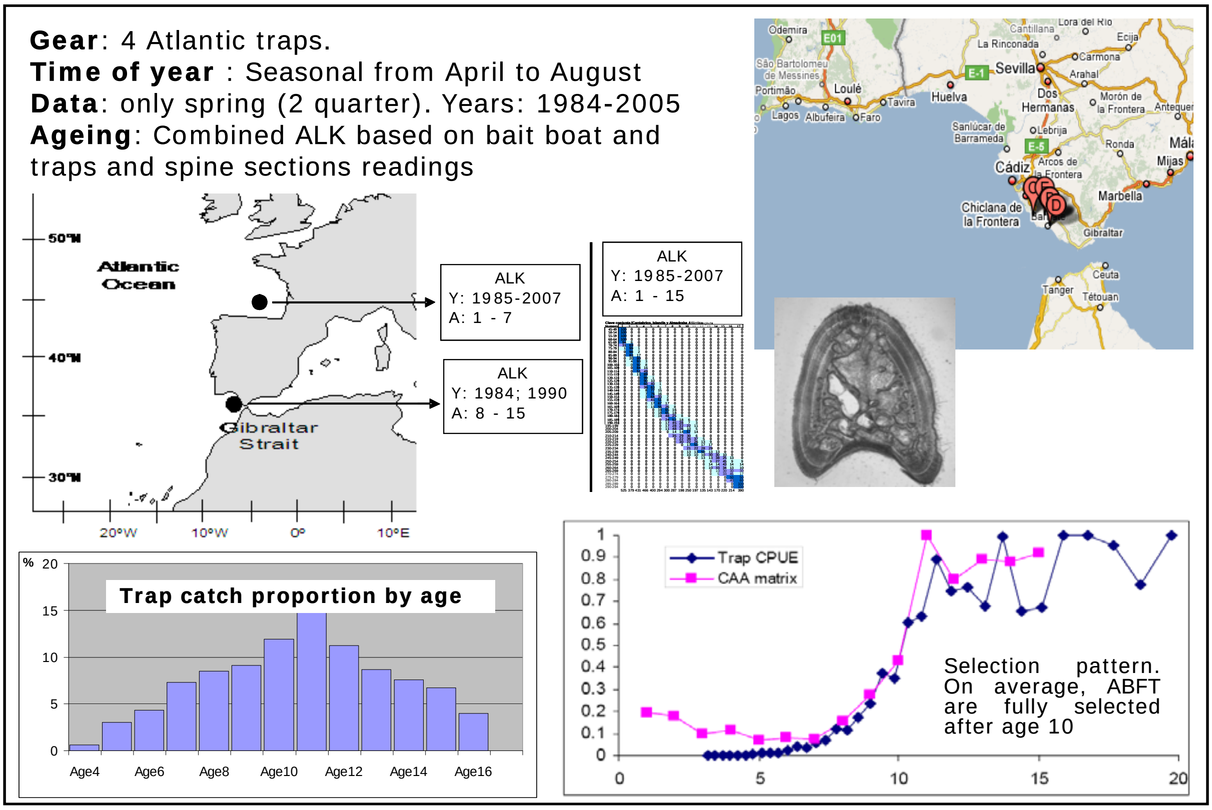

Figure 5. Description of the Spanish Atlantic traps and the ageing process.

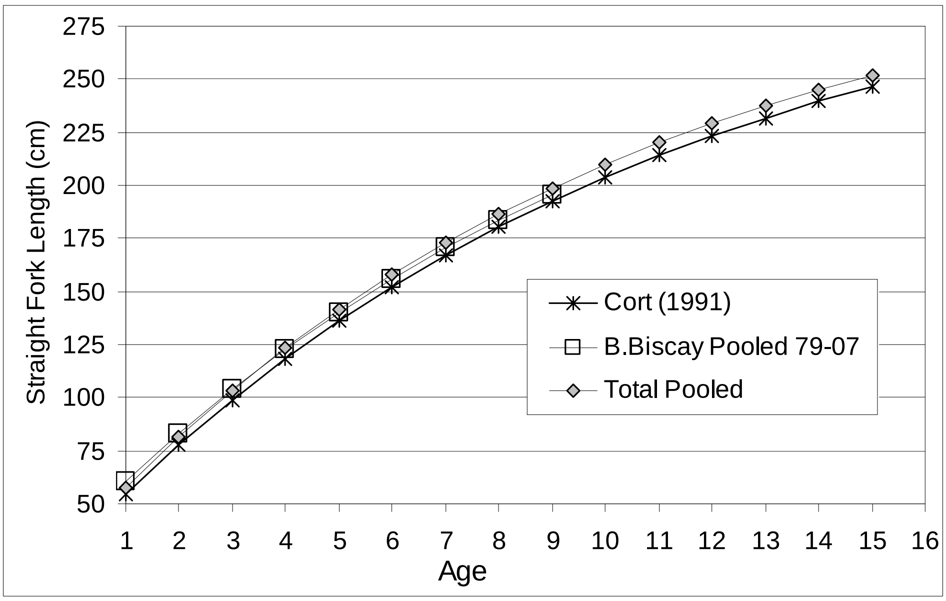

Figure 6. Growth equation obtained from the pooled ALKs and the currently used growth curve for the East Atlantic and Mediterranean stock.

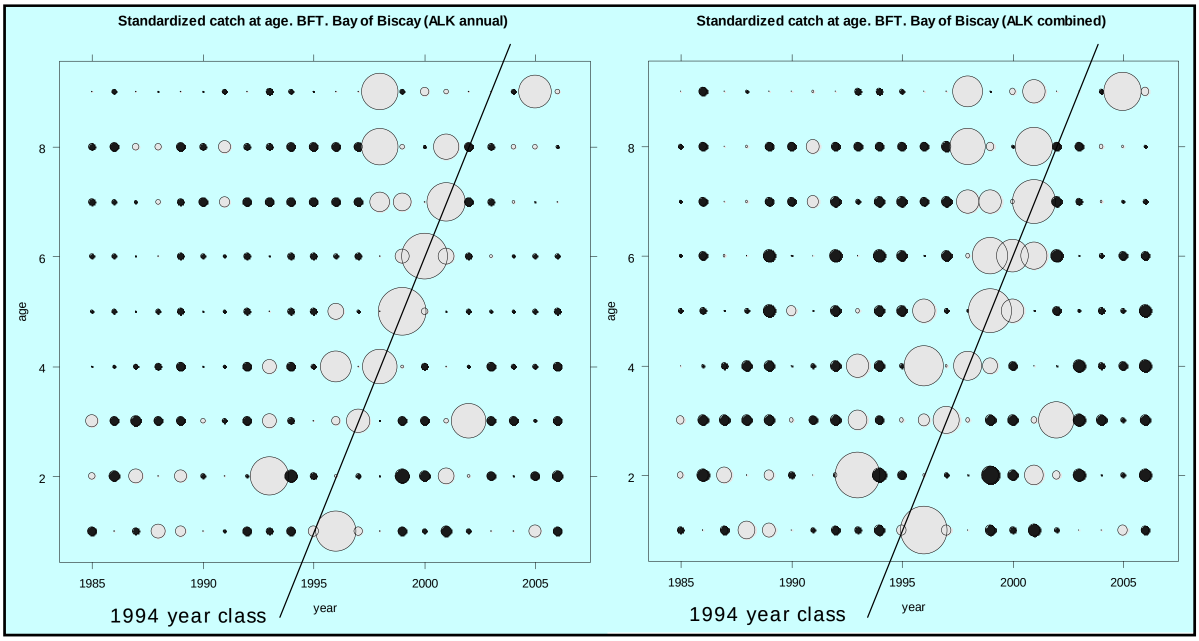

Figure 7. ABFT standardised catch at age from the Bay of Biscay baitboat fishery, on the left obtained by applying annual age length keys (ALK) and on the right by applying a combined one.

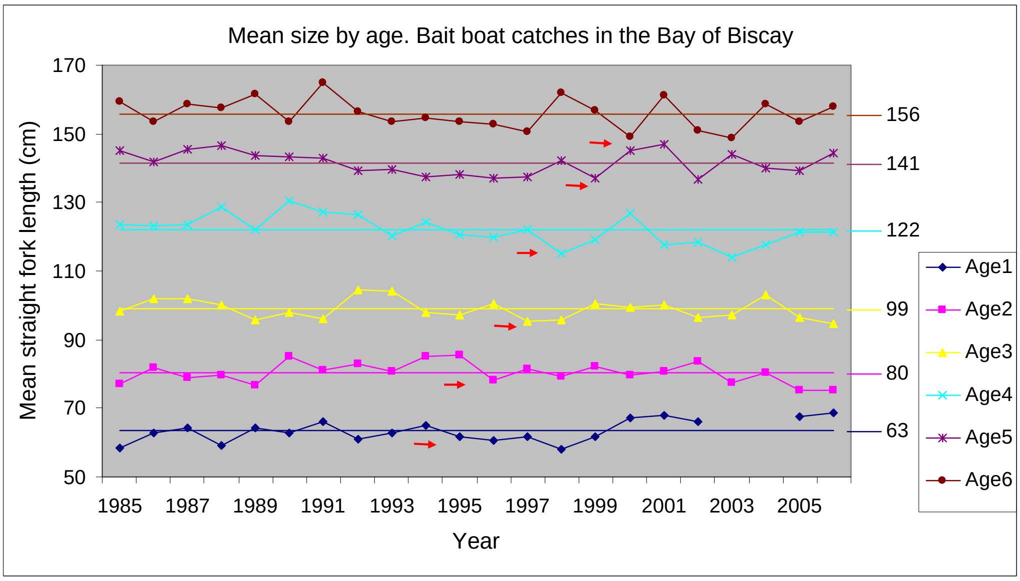

Figure 8. ABFT mean size (straight fork length) at age in the Bay of Biscay baitboat catches from 1985 to 2006. Arrows indicate the 1994 year class.

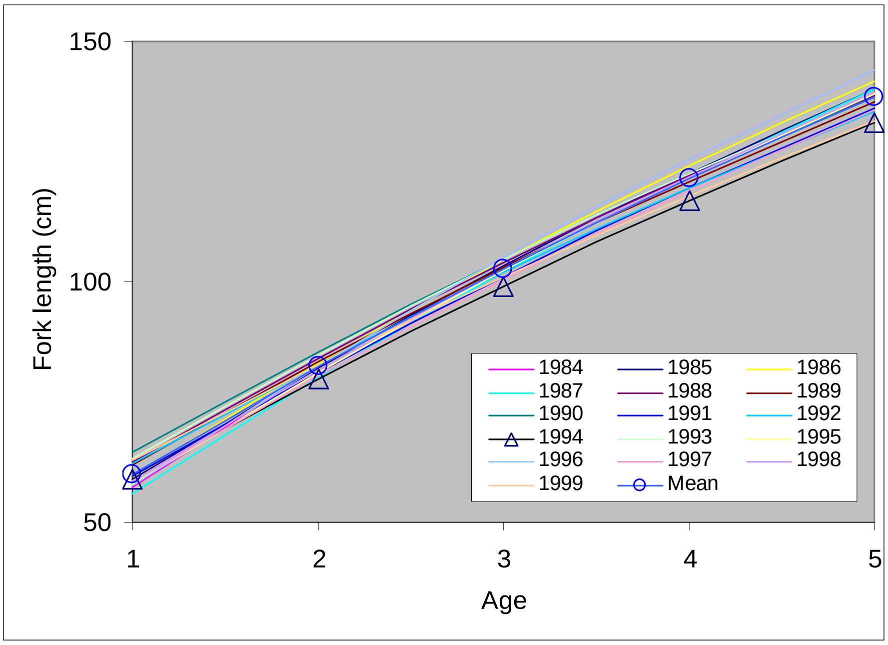

Figure 9. Growth equations of the different cohorts fitted to ages from 1 to 5 years and from the catch of the Bay of Biscay baitboat fishery. The triangle indicates the 1994 year class and the circle the mean value of the remaining cohorts.

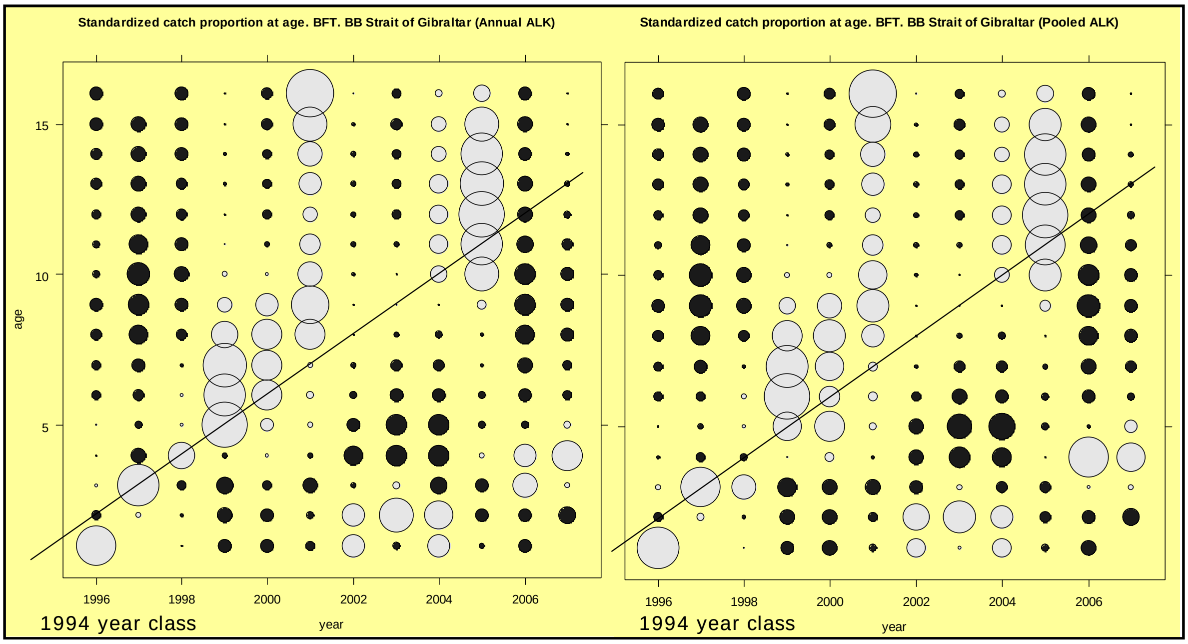

Figure 10. ABFT standardized catch proportion at age from the Strait of Gibraltar baitboat fishery (left) obtained by applying annual age length keys (ALK) and by applying a pooled one (right).

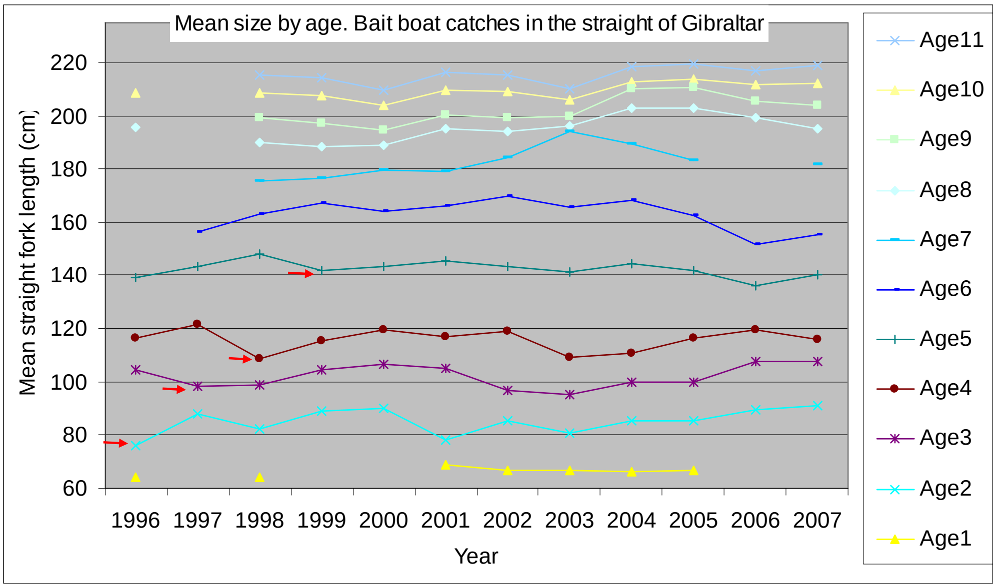

Figure 11. ABFT mean size (straight fork length) at age in the Strait of Gibraltar baitboat catches from 1996 to 2007.

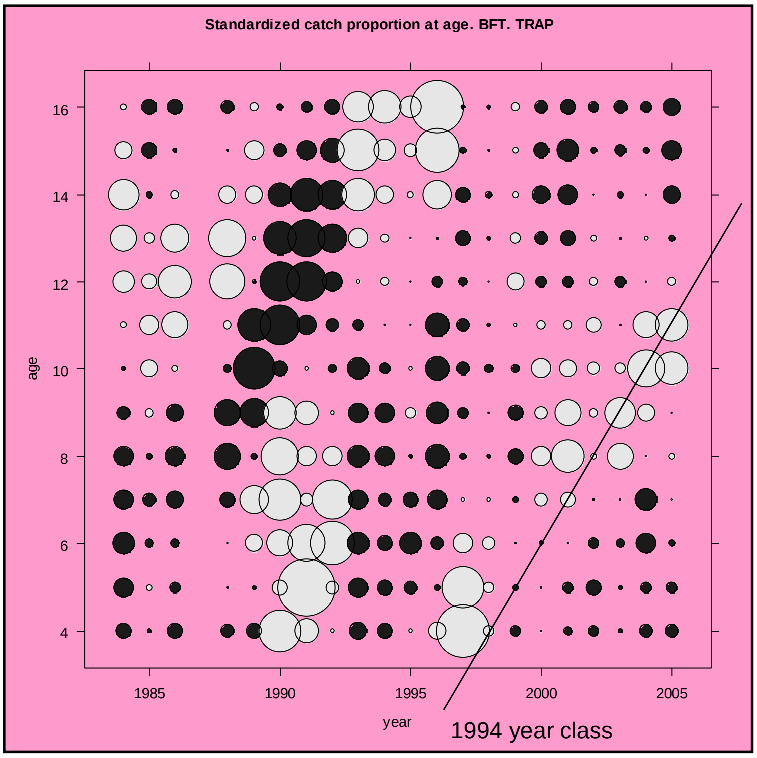

Figure 12. ABFT standardised catch proportion at age from the Spanish Atlantic traps by applying a combined Age Length Key (ALK). Ages represented: 4 to 16+ years.

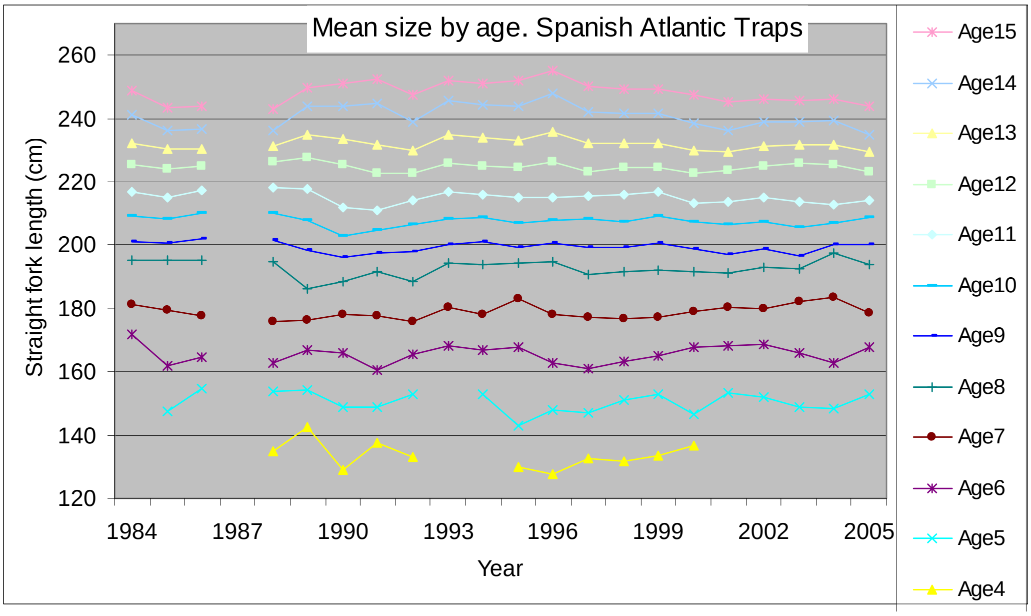

Figure 13. ABFT mean size (straight fork length) at age in Spanish Atlantic traps from 1984 to 2005.